eCook Kenya Prototyping

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Acknowledgement

The findings presented in this report would not have been possible without turning our kitchen into a kitchen laboratory. Therefore, I am eternally grateful to my partner Karen, who taught me to cook traditional Kenyan dishes and tolerated a worktop full of nuts, bolts and batteries. Her willingness to experiment and share her culinary experiences created an unexpectedly rich learning opportunity, for which we are very grateful. We are also grateful to everyone who came to visit our kitchen laboratory and shared their insights with us, including the staff of ACTS, both those named as authors and the supporting staff. Finally, we thank the donors, UK Aid, EPSRC, RCUK and DECC (now BEIS) via the USES (Understanding Sustainable Energy Solutions) programme, specifically *The Next Generation of Low Cost Energy Efficient Products for the 'Bottom of The Pyramid'*, or *Low Cost Technologies* (*LCT*) project. Additional analysis was carried out under the Modern Energy Cooking Services (MECS) programme, also funded by UK Aid.

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Executive Summary

This report presents the key learning points from the cooking diaries study to inform the future development of eCook (battery-supported electric cooking) within Kenya. The aim of this study is to gain a deeper understanding of how Kenyan households cook and how compatible this is with electricity. The eCook Kenya prototypes were designed to demonstrate that it is possible to cook on battery-supported electricity and to obtain feedback from end-users and other key stakeholders that could guide the design of the next generation of prototypes.

These prototyping activities have shown that it is already possible to assemble a compact, affordable and energy-efficient prototype eCook device using mass-produced components. Key to achieving affordability, energy-efficiency, reliability and portability is omitting the inverter by using DC cooking appliances and switching to lithium ion battery storage. In particular LiFePO4 is already becoming widely adopted by the off-grid solar industry, as one of the safest and most affordable lithium ion technologies. Building supply chains for high quality DC cooking appliances and lithium ion batteries of sufficient capacity (>100Wh) will be instrumental in enabling widespread adoption of eCook products/services.

Four prototypes were constructed, each with slightly different design philosophies (Figure ES-1):

1. The eCook Kenya Mark 1 Prototype simply needed to show that battery-supported cooking was possible. It was built on a very low budget, using readily available components from conventional suppliers. It used 1kWh lead acid battery storage charged from an AC battery-charger. Off-the-shelf AC cooking appliances were powered using an inverter. However, it could only operate at high power (1.2kW) for under 10 minutes, as lead acid batteries are not well matched with high C-rate applications such as eCooking.
2. The eCook Kenya Mark 2 Prototype (the eCookBox) was designed to showcase the superior performance of lithium ion. It replaced the Mark 1's 1kWh lead acid battery storage with 1.2kWh LiFePO4, greatly extending the amount of time it could operate for. This prototype was used to cook a blend of Kenyan and international dishes for 2 people for 1 year, powered by a blend of solar and grid electricity via a battery charger. However, it was still very bulky and heavy.
3. The eCook Kenya Mark 3 Prototype (the eCookBucket) was designed to show how simple a solar electric cooking system could be. In the same way that solar lanterns integrated the whole system into a single unit, the eCookBucket used a DC cooking appliance and integrated 0.24kWh LiFePO4 battery-storage into the body of the appliance, leaving just the PV panel outside. However, it was not possible to take this on an aeroplane due to restrictions on travelling with higher capacity lithium ion batteries.
4. The eCook Kenya Mark 4 Prototype upgraded to the ultra-efficient Electric Pressure Cooker (EPC) and was designed for showcasing at international conferences, with the LiFePO4 storage transported as a power bank in hand luggage.

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Figure ES-1: The evolution of the eCook Kenya Prototypes: the lead acid AC Mark 1 (top left), the LiFePO4 AC Mark 2 eCookBox (middle left), the DC battery-integrated LiFePO4 Mark 3 eCookBucket (right) and the ultra-efficient DC LiFePO4 Mark 4 (bottom left).

The four eCook Kenya prototypes were able to showcase the idea of battery-supported cooking at a range of international events in Rwanda, Kenya, India, Spain and the UK. They successfully communicated the concept to a broad range of stakeholders in the clean cooking and electrification spheres, who it is hoped will play a vital role in enabling eCooking around the world.

This research is funded by DfID/UK Aid, EPSRC, RCUK & DECC (now BEIS) through the USES programme.

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1 Introduction

This report presents one part of the detailed in-country research carried out to explore the market for eCook in Kenya. In particular, this in-country work aims to gain much greater insight into culturally distinct cooking practices and explore how compatible they are with battery-supported electric cooking. The report is rich with detail and is intended to provide decision makers, practitioners and researchers with new knowledge and evidence.

This report presents the key learning points from the prototyping to inform the future development of eCook within Kenya. It is one component of a broader study designed to increase global understanding of the demand from various BoP segments with respect to low-cost energy-efficient technologies, and how such products can be sustainably developed and deployed in developing countries to have large-scale impact. *The Next Generation of Low Cost Energy Efficient Products for the 'Bottom Of The Pyramid'*, or *Low Cost Technologies* (*LCT*) project was funded by UK Aid, EPSRC, RCUK and DECC (now BEIS) via the USES (Understanding Sustainable Energy Solutions) programme: http://www.sussex.ac.uk/spru/research/projects/lct.

A much deeper analysis of the data collected during this project was supported by the Modern Energy Cooking Services (MECS) programme, which included the writing of this report. The overall aims of the LCT project, plus the series of interrelated projects that precede and follow on from it are summarised in in *Appendix A: Problem statement and background to LCT eCook project*.

1.1 Background

1.1.1 Context of the potential landscape change by eCook

The use of biomass and solid fuels for cooking is the everyday experience of nearly 3 billion people. This pervasive use of solid fuels and traditional cookstoves results in high levels of household air pollution with serious health impacts; extensive daily drudgery required to collect fuels, light and tend fires; and environmental degradation. Where households seek to use 'clean' fuels, they are often hindered by lack of access to affordable and reliable electricity and/or LPG. The enduring problem of biomass cooking is discussed further in *Appendix A: Problem statement and background to LCT eCook project*, which not only describes the scale of the problem, but also how changes in renewable energy technology and energy storage open up new possibilities for addressing it.

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1.1.2 Introducing 'eCook'

eCook is a potentially transformative battery-supported electric cooking concept designed to offer access to clean cooking and electricity to poorer households (HHs) currently cooking on charcoal or other polluting fuels (Batchelor, 2013, 2015a, 2015b). Enabling affordable electric cooking sourced from renewable energy technologies could also provide households with sustainable, reliable, modern energy for a variety of other purposes.

A series of initial feasibility studies were funded by DfID UK AID under the PEAKS mechanism (available from https://elstove.com/dfid-uk-aid-reports/). Slade (2015) investigated the technical viability of the proposition, highlighting the need for further work defining the performance of various battery chemistries under high discharge and elevated temperature. Leach & Oduro (2015) constructed an economic model, breaking down PV-eCook (Figure 1) into its component parts and tracking key price trends, concluding that by 2020, monthly repayments on PV-eCook were likely to be comparable with the cost of cooking on charcoal. Brown & Sumanik-Leary's (2015), review of behavioural change challenges highlighted two distinct opportunities, which open up very different markets for eCook:

- PV-eCook uses a PV array, charge controller and battery in a comparable configuration to the popular Solar Home System (SHS) and is best matched with rural, off-grid contexts.
- Grid-eCook uses a mains-fed AC charger and battery to create distributed HH storage for unreliable or unbalanced grids and is expected to best meet the needs of people living in urban slums or peri-urban areas at the fringes of the grid (or on a mini-grid) where blackouts are common.

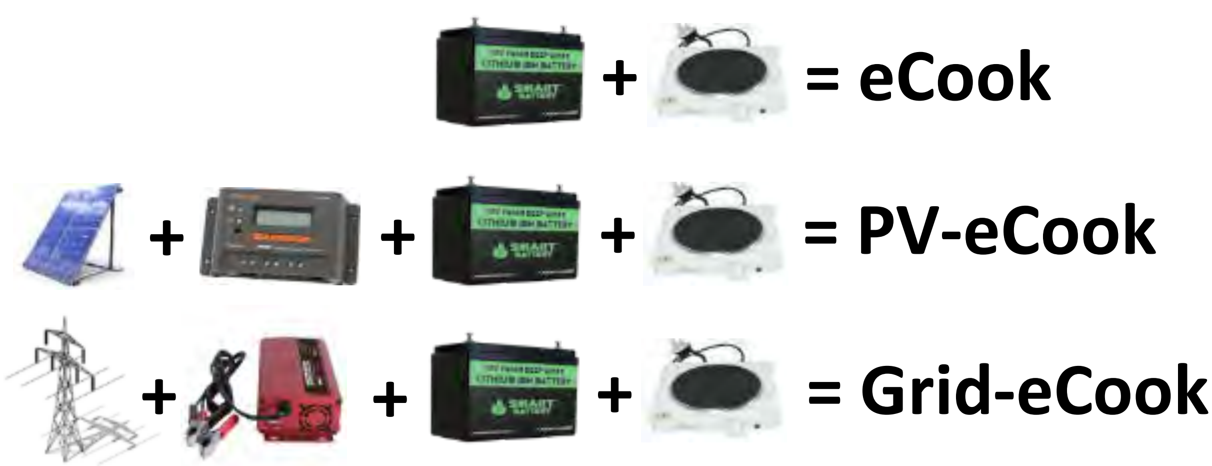

Figure 1: Pictorial definitions of 'eCook' terminology used in this report.

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1.1.3 eCook in Kenya

Given the technical and socio-economic feasibility of the systems in the near future, Gamos, ACTS, the University of Sussex and UIU have sought to identify where to focus initial marketing for eCook. Each country has unique market dynamics that must be understood in order to determine which market segments to target are and how best to reach them. Leary et al. (2018) carried out a global market assessment, which revealed Kenya as the most viable context for PV-eCook, as it has the highest mobile money penetration rate and the second largest market for pico-solar products and SHS in the world.

The accompanying reports from the other activities carried out under the LCT project in Kenya can be found at: http://www.sussex.ac.uk/spru/research/projects/lct.

1.2 Aim

The aim of this study is to design, assemble and test an eCook concept prototype in Kenya.

In particular, the objectives of the study are:

- To design the prototype around the needs and aspirations of Kenyan cooks.
- To use the prototype to demonstrate the concept of cooking on battery-supported electricity to key stakeholders.

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2 Design Philosophies

The eCook Kenya prototypes were designed to demonstrate that it is possible to cook on battery-supported electricity and to obtain feedback from end-users and other key stakeholders that could guide the design of the next generation of prototypes.

Four prototypes were constructed, each with slightly different design philosophies:

1. The eCook Kenya Mark 1 Prototype simply needed to show that battery-supported cooking was possible. It was built on a very low budget, using readily available components from conventional suppliers. It used 1kWh lead acid battery storage charged from an AC battery-charger. Off-the-shelf AC cooking appliances were powered using an inverter. However, it could only operate at high power (1.2kW) for under 10 minutes, as lead acid batteries are not well matched with high C-rate applications such as eCooking.
2. The eCook Kenya Mark 2 Prototype (the eCookBox) was designed to showcase the superior performance of lithium ion. It replaced the Mark 1's 1kWh lead acid battery storage with 1.2kWh LiFePO4, greatly extending the amount of time it could operate for. This prototype was used to cook a blend of Kenyan and international dishes for 2 people for 1 year, powered by a blend of solar and grid electricity via a battery charger. However, it was still very bulky and heavy.
3. The eCook Kenya Mark 3 Prototype (the eCookBucket) was designed to show how simple a solar electric cooking system could be. In the same way that solar lanterns integrated the whole system into a single unit, the eCookBucket used a DC cooking appliance and integrated 0.24kWh LiFePO4 battery-storage into the body of the appliance, leaving just the PV panel outside. However, it was not possible to take this on an aeroplane due to restrictions on travelling with higher capacity lithium ion batteries.
4. The eCook Kenya Mark 4 Prototype upgraded to the ultra-efficient Electric Pressure Cooker (EPC) and was designed for showcasing at international conferences, with the LiFePO4 storage transported as a power bank in hand luggage.

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3 The eCook Kenya Mark 1 Prototype

The first eCook Kenya prototype was designed simply to show that cooking on battery-supported electricity was possible. It was built using low cost components totalling 27,00 KES (270 USD) available from small solar suppliers on Nairobi's River Road (Figure 2 and Table 1). It is widely known that lithium ion batteries have superior cycle life to lead acid, which make them economically attractive for long-term installations. However, as this prototype was built for temporary device until suitable lithium batteries could be sourced, this was considered acceptable. The Mark 1 prototype used off-the-shelf AC appliances, offering the user a comparable experience to cooking on grid electricity, however only for a limited time.

Figure 2: Cooking sukuma wiki with the eCook Kenya Mark 1 Prototype.

The prototype was able to power a standard electric hotplate via an inverter, however at full power (1.2kW), it operated for less than 10 minutes. With only 1kWh of battery storage, discharge rates exceeded C1, which is extremely detrimental to lead acid batteries for several reasons:

- It reduces the cycle life of lead acid batteries considerably.
- It pulls down the voltage, tripping the inverter's low voltage disconnect and disconnecting the load prematurely. The voltage SoC curve for lead acid changes significantly with C rate – at high C rates, it drops off rapidly (Figure 3).

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- It reduces the useable capacity – battery capacity is given at a specific discharge rate. These Koshin batteries state "12V 20Ah 20hr", indicating that they will only deliver their rated 0.24 Wh capacity if that energy is drawn out over a 20hr period, i.e. C/20. For lead acid batteries, the capacity diminishes significantly at high C rates (Figure 4).

What is more, it is not recommended to discharge lead acid batteries below 50% DoD (Depth of Discharge), effectively reducing their capacity to 0.5kWh. Combining this with the effect of C-rate on discharge capacity, this leaves under 20% of their original capacity (0.2kWh). What is more, the effect of C-rate on cell voltage meant that the inverter's low voltage disconnect tripped even earlier, reducing the usable capacity even further. As a result, the fact that it operated for just 10 minutes is not surprising, as this represents 0.16kWh of useful capacity under these conditions.

Reducing the power consumption of the load and reducing the duration over which power is drawn were both viable options for increasing the duration of cooking. The hotplate could operate on low power (400W) for approximately half an hour. The EPC could complete a full cooking cycle with small amounts of food inside, as the insulation means it only draws power occasionally and pressurisation means it reduces the total cooking time.

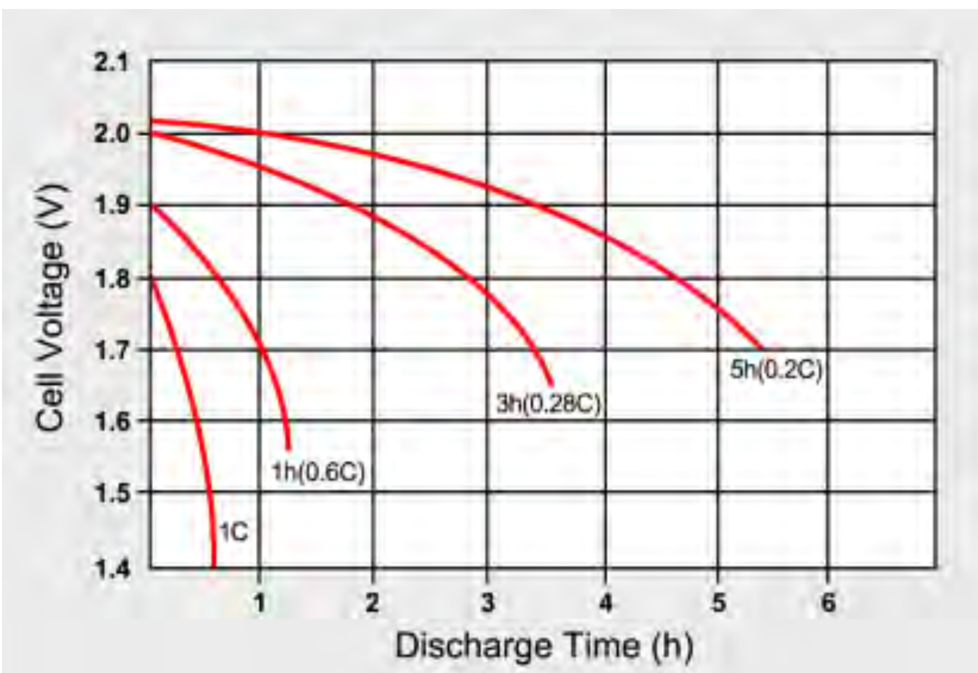

Figure 3: Effect of rapid discharge on cell voltage for lead acid batteries (Battery University, 2019).

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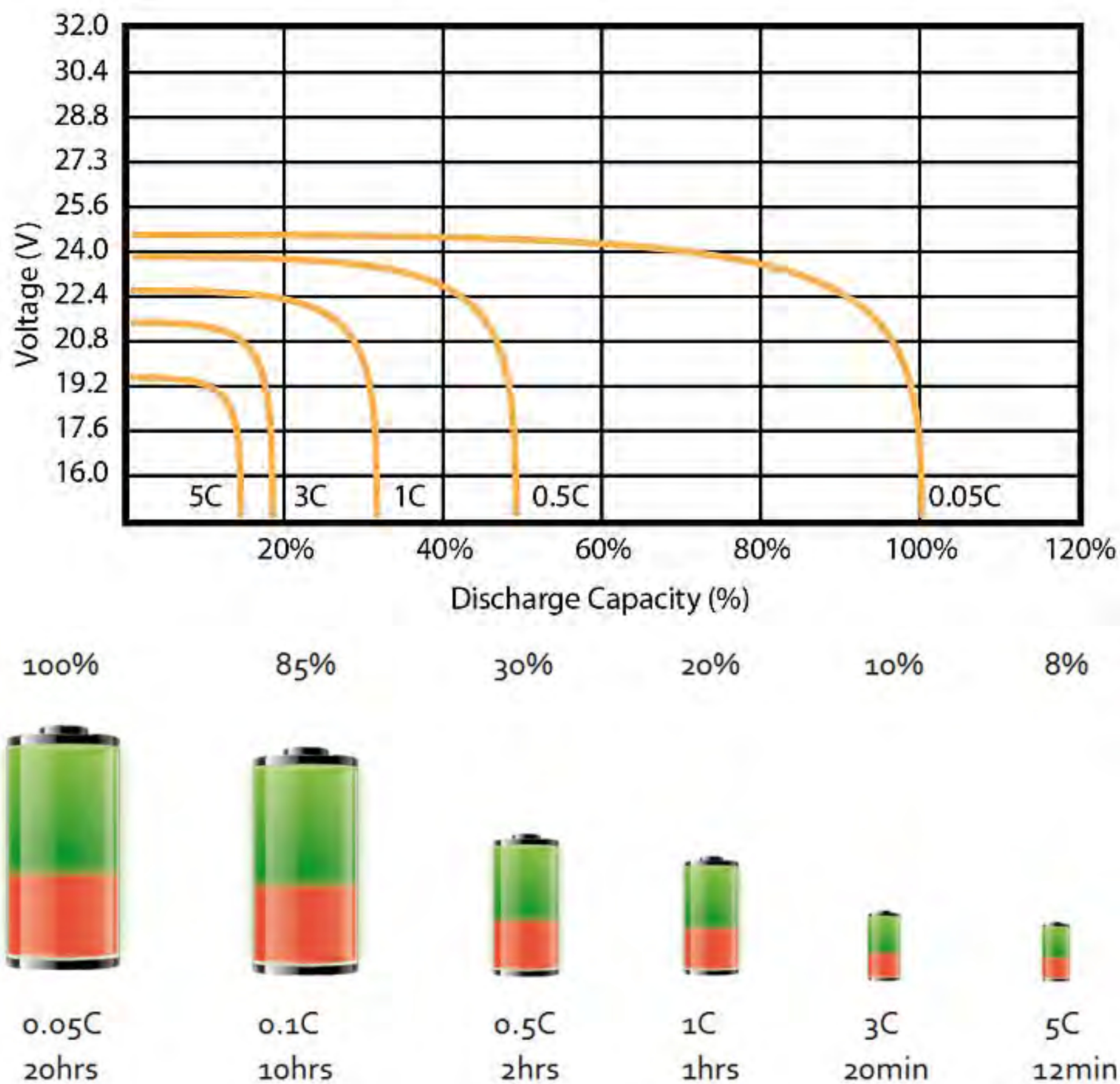

Figure 4: Effect of C-rate on lead acid battery storage capacity, based upon 50-70% DoD (Victron Energy, 2019).

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Table 1: Components list for eCook Kenya Mark 1 Prototype.

Component	Description	Cost (KES)	Cost (USD)
Battery storage	4* Koshin 12V 24 Ah lead acid batteries in 24V bank	8,000	80
Charger	5A lead acid battery charger	2,000	20
Inverter	1,500W 24V ASE Solar	7,000	70
Appliances	AC hotplate	3,000	30
	AC Electric Pressure Cooker (EPC)	7,000	70
	TOTAL:	27,000	270

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4 The eCook Kenya Mark 2 Prototype (the eCookBox)

The main aim of the eCook Kenya Mark 2 Prototype was to enable cooking for longer durations. This was achieved by upgrading the lead acid batteries to $LiFePO_4$. Figure 5 shows that lithium ion offers greater DoD and C-rate has a much less significant effect on both cell voltage and discharge capacity. As a bonus, the cycle life is estimated to be 3-5 times higher and is less sensitive to C-rate. The cells are protected by a BMS (Battery Management System), which means they will not discharge to levels that would damage the battery, unlike the lead acid batteries, which rely on external low voltage disconnect devices, leaving them vulnerable to deep discharge that will reduce their cycle life.

The eCook Kenya Mark 2 Prototype (or eCookBox) was built in parallel to the eCook Tanzania Mark 1 Prototype, which is described in detail in the *eCook Tanzania Prototyping Final Report* (Leary *et al.,* 2019). A detailed technical description of this model, the technical challenges faced and the key learning points are given in Leary *et al.* (2019), with an overview presented here.

Unlike its Tanzanian counterpart, which was mainly used for demonstrations, the eCookBox was used for everyday cooking in our 'kitchen laboratory' in Nairobi. It was used to cook a mixture of Kenyan and international cuisine for 2 people for approximately 1 year. The batteries were charged from a 200W solar array (Figure 9), which was sufficient during the dry season, however they required topping up from the grid during the rainy season. A range of different electric cooking appliances were used to explore their compatibility with Kenyan cuisine and importantly, their energy-efficiency (Figure 10 and Figure 7).

The eCook Tanzania Mark 1 & Kenya Mark 2 Prototypes consisted of 1.2kWh $LiFePO_4$ battery storage, an 800W inverter/charger, a 30A solar controller and set of energy-efficient electric cooking appliances. It could be charged from solar panels and/or the grid, making it a hybrid PV/Grid-eCook system. It was sized to allow a small family (2-3 people) cooking efficiently using energy-efficient cooking practices to be able to do the majority of their cooking. For peaks in demand (many relatives coming to visit) or dips in supply (very cloudy days and/or blackouts lasting longer than a day), it would need to be supported by an alternative stove.

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The prototyping carried out in Kenya and Tanzania showed that in 2018, many of the basic components required to build a cost-effective and technically optimised eCook system were still not available. In particular, higher capacity lithium ion batteries and DC cooking appliances were very specialised pieces of equipment that required direct importation. The total cost for all the components came in at 1,480 USD (Table 2), however there is significant scope for optimisation. As a result, a total cost of 500USD for a mass-produced unit in 2020 seems feasible.

The main justification for component choice was availability. Over 20 solar suppliers were contacted in Nairobi, however, only 1 was able to supply lithium ion batteries of above 10Ah. The 12V 20 Ah LiFePO4 batteries used in the eCook TZ Mark 1 and eCook Kenya Mark 2 prototypes were obtained on the good will of Orb Energy in Nairobi as a spare part for their Solectric 600 solar home system. These are the biggest lithium ion batteries they currently supply and are not usually sold separately.

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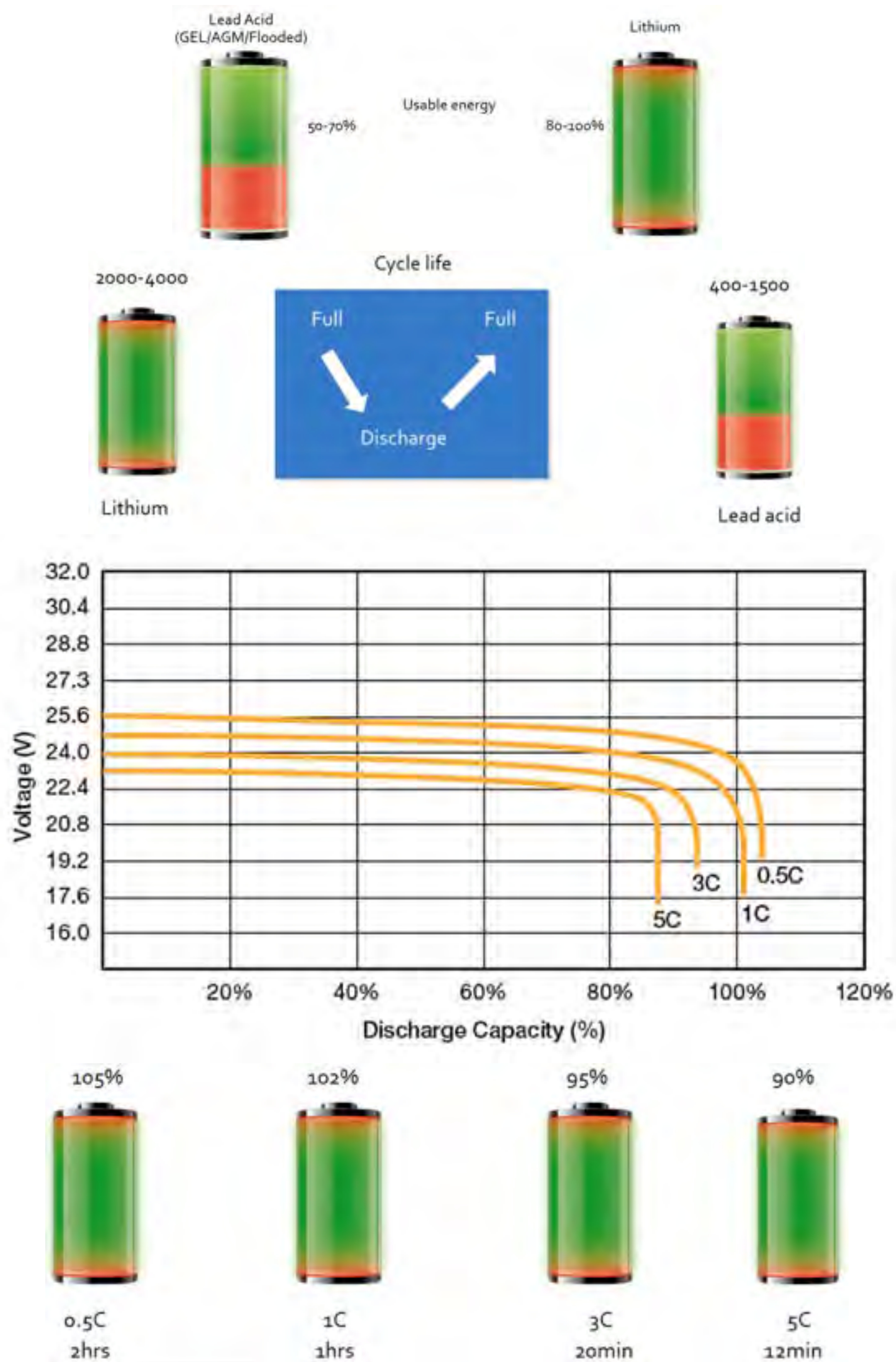

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Figure 5 Effect of C-rate on lithium ion battery storage capacity, based upon 50-70% DoD (Victron Energy, 2019).

Table 2: Parts list for eCook Kenya Mark 2 Prototype (eCookBox) components.

Component	Specification	Brand	Supplier	No.	Unit cost	Total cost
Box	Tough Tote		Game	1	25 USD (60,000 TZS)	25 USD
Batteries	12V 20Ah LiFePO4	Optimum Nano-Energy	Orb Energy	5	120 USD (12,000 KES)	600 USD
Solar charge controller	30A LiFePO4 compatible		Amazon.co.uk	1	40 USD (30 GBP)	40 USD
Inverter/charger	800W LiFePO4 compatible	Victron	Centre for Alternative Technologies	1	600 USD (60,000 KES)	600 USD
Electric pressure cooker	850W, 4 litres	Singsung	Small electrical appliance store	1	50 USD (120,000 TZS)	50 USD
Thermo-pot	750W, 3 litres	UMS	Small electrical appliance store	1	55 USD (130,000 TZS)	55 USD
Rice cooker	700W, 5 litres	Von Hotpoint	Small electrical appliance store	1	20 USD (50,000 TZS)	20 USD
Plug-in energy meters	3kW max power	Energenie	Amazon.co.uk	2	20 USD (15 GBP)	40 USD
Misc. components	13A 3-way extension cable, DC cables, screws, PowerPole connectors, 30A blade fuses & holders, cable ties, LED light, USB cable, rope, plywood mounting board	Various	Amazon.co.uk, Orb Energy, small local hardware stores	Total for all	50 USD	50 USD
					TOTAL:	***1,480 USD***

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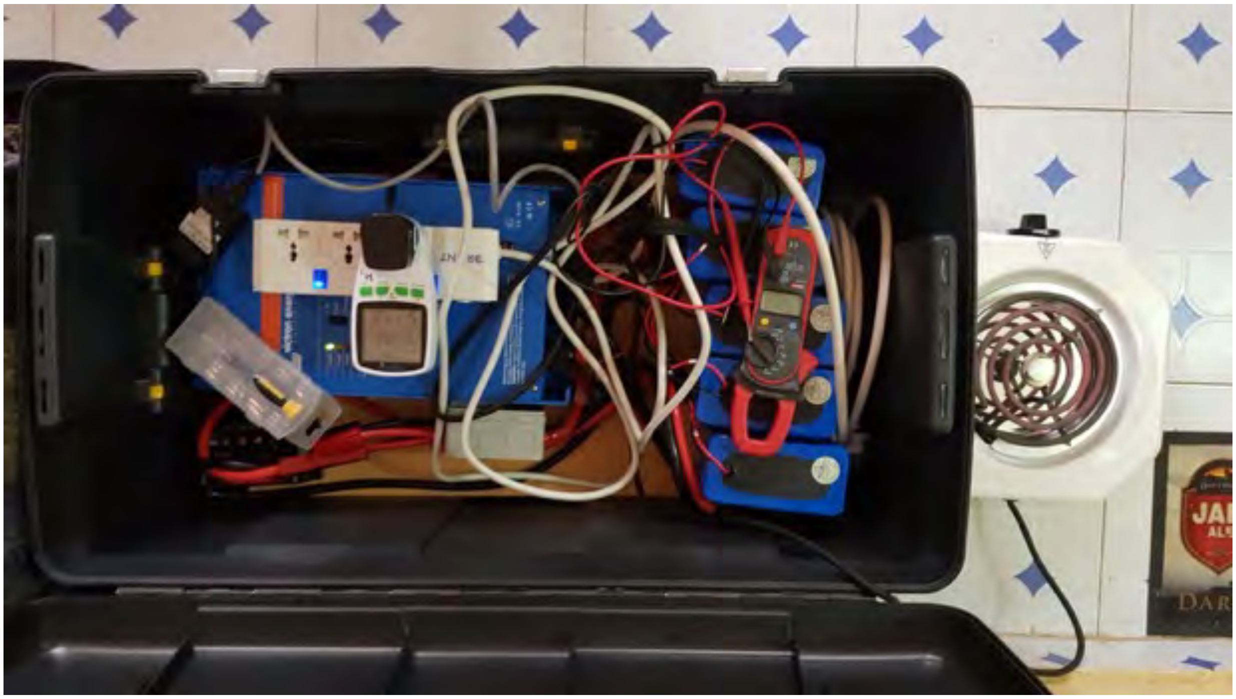

Figure 6: Testing the eCook Kenya Mark 2 Prototype with an AC electric hotplate.

Figure 7: Experimenting with different energy-efficient appliances to enable more cooking to be done on the battery-supported system.

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Figure 8: Inside the eCook Kenya Mark 2 Prototype, or 'eCookBox'.

Figure 9: The 200W solar array on top of the 'kitchen laboratory' where the 'eCookBox' was installed.

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Figure 10: Experimenting with adding insulation to a halogen oven to reduce energy losses to enable more cooking to be done on the battery-supported system.

Figure 11: Showcasing the eCookBox at EcoZoom East Africa, Nairobi.

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Figure 12: Showcasing the eCookBox at the KAM Renewable Energy and Energy Efficiency Fair in Nairobi.

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5 The eCook Kenya Mark 3 Prototype: The eCookBucket

The eCookBucket is the solar lantern of the solar electric cooking world. Unlike either of its predecessors, it is light and compact, with all the components required to cook integrated into a single housing. As a result, it is highly portable, enabling cooking in any location. The key enabler for the eCookBucket was the DC cooking appliance. Eliminating the inverter from the system greatly reduced its size and weight, plus the low power rating of the DC appliance meant that it could be powered by a single 20AH 12V LiFePO4 battery pack. The DC appliance was obtained as a sample directly from a factory in China during parallel eCook prototyping activities in Myanmar (Leary, Htay, *et al.*, 2019).

The eCookBucket is very simple, comprising just three essential components: a DC rice cooker, a LiFePO4 battery pack and a circuit breaker. It can be charged from the grid using a simple LiFePO4 battery charger or off-grid using solar PV. The total cost for the grid-connected version was 270 USD and 430 USD for the off-grid solar version (, with foldable solar panels to make it more portable for showcasing at events. However, there is considerable room for optimisation of the costs:

- The battery was obtained as a spare part for a solar home system at a very high cost of 833 USD/kWh. Current factory gate prices in China for LiFePO4 battery packs range from 200-350 USD/kWh
- The solar panels were foldable to make transporting the prototype to events easier. They were obtained for a cost of 2.6 USD/W, whereas standard crystalline silicone PV panels retail for below 1 USD/W.
-

Table 3: Parts list for eCookBucket with grid-connected charging.

Component	Description	Cost (USD)
Battery storage	1* 12V 20Ah LiFeP04 Optimum Nano Energy Battery Pack	200
Charger	5A LiFePO4 battery charger	20
Circuit breaker	50A DC Midnite Solar resettable circuit breaker	20
Appliance	DC rice cooker	30
	TOTAL:	270

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Table 4: Optional additional parts for off-grid solar charging.

Component	Description	Cost (USD)
Solar panel	60W foldable thin film PV	150
Solar charge controller	30A LiFePO4 compatible solar charge controller	30
	TOTAL:	180

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Figure 13: Experimenting with cooking ugali with the DC rice cooker. The non-stick pot was very easy to clean, but the temperature sensor designed to turn the appliance onto warm mode after rice had cooked could not be overridden without taking the appliance apart, meaning that cooking times were extended considerably.

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Figure 14: The 'bucketization' of the eCookBucket. A simple household bucket was used to extend the body of the DC rice cooker around the battery. The only other component is a DC circuit breaker, which also functioned as an on/off switch.

This research is funded by DfID/UK Aid, EPSRC, RCUK & DECC (now BEIS) through the USES programme.

Figure 15: Showcasing the eCookBucket to dignitaries from the Ministry of Energy at the KAM Renewable Energy and Energy Efficiency Fair in Nairobi, July 2018.

Figure 16: Showcasing the eCookBucket at the CCA Investment Forum and GOGLA Unlocking Solar Capital event at KICC, Kigali, Rwanda in November 2018. The eCookBucket (left) takes an alternative design philosophy to the solar electric cooker shown on the right. The eCookBucket optimises energy demand using energy-efficient appliances and practices, resulting in a portable device with a much smaller and much cheaper battery bank.

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Figure 17: Showcasing the eCookBucket alongside solar thermal cookers at the S@ccess 2nd International Conference on Solar Technologies & Hybrid Mini Grids to Improve Energy Access in Palma de Mallorca, Spain. A meal of kales and rice for 2 people was cooked by steaming the kales above the rice.

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6 The eCook Kenya Mark 4 Prototype

The fourth prototype was designed for showcasing at international conferences. Airline restrictions prevent lithium ion batteries greater than 100Wh from being transported by passengers. As a result, when attending the S@ccess 2nd International Conference on Solar Technologies & Hybrid Mini Grids to Improve Energy Access in Palma de Mallorca, Spain, the eCookBucket was transported without the battery and a replacement was purchased locally (Figure 17).

Unfortunately, 100Wh is not enough to cook most foods, so a battery with marginally higher capacity was selected for the demonstration. A replacement battery for a golf cart was chosen, as it had sufficient capacity to cook a simple meal (Figure 17), but had a well finished exterior, similar to a power bank. As a result, it has been possible to travel to several international destinations with the battery pack in hand luggage. The golf cart battery was modified to remove the terminals and install a USB and 12V socket (Figure 19).

The advantage of the external battery is that it is much easier for people to conceptualise how much energy has gone into that meal when they can physically see the size of the battery pack. Whilst the eCookBucket was ideal for demonstrating the concept of the DC battery-integrated eCooking appliance, this prototype enabled passers-by to clearly see where the energy was coming from and how much was stored.

The other key upgrade was replacing the DC rice cooker with a DC Electric Pressure Cooker (EPC). This was also obtained as a sample directly from the factory, Tesga Power, alongside a range of other DC cooking appliances (Figure 20). The EPC is able to cut the cooking time of long boiling dishes like beans in half, enabling it to cook both ‘light’ (e.g. rice, kales) and ‘heavy’ (e.g. beans, tripe) foods. This could be achieved without running the 200Wh battery flat, if using efficient cooking practices, for example just boiling ‘heavy foods’ and omitting the frying step.

At 260 USD for the grid-connected version (Table 5), the Mark 4 Prototype had an almost identical cost to the Mark 3 Prototype. It could also be upgraded to off-grid solar for an additional 180 USD (Table 4). Again, there is considerable room for cost optimisation, in particular the battery and PV panels.

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Table 5: Parts list for eCook Kenya Mark 4 Prototype with grid-connected charging.

Component	Description	Cost (USD)
Battery storage	1* 12V 16Ah LiFeP04 Re-Lion Battery Pack	200
Charger	5A LiFePO4 battery charger	20
Circuit breaker	30A DC automotive blade fuse	10
Appliance	Tesga Power DC Electric Pressure Cooker (EPC)	30
	TOTAL:	260

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Figure 18: Showcasing the eCook Kenya Mark 4 Prototype at the GOGLA India Distributed Energy Forum in New Delhi in January 2019.

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Figure 19: The modified golf-cart battery after removing the battery terminals and rebranding.

Figure 20: A range of DC cooking appliances manufactured by Tesga Power on display at the MECS East Africa Launch in May 2019 in Nairobi Kenya. From top to bottom: a DC kettle, DC hotplate, 5 litre DC EPC and 2.8 litre DC EPC. On the left is the 1.2kWh LiFePO4 battery bank from the eCookBox.

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7 Conclusion

These prototyping activities have shown that it is already possible to assemble a compact, affordable and energy-efficient prototype eCook device using mass-produced components. Key to achieving affordability, energy-efficiency, reliability and portability is omitting the inverter by using DC cooking appliances and switching to lithium ion battery storage. In particular LiFePO4 is already becoming widely adopted by the off-grid solar industry, as one of the safest and most affordable lithium ion technologies. Building supply chains for high quality DC cooking appliances and lithium ion batteries of sufficient capacity (>100Wh) will be instrumental in enabling widespread adoption of eCook products/services.

The findings from this study will be combined with those from the other activities that have been carried under the eCook Kenya Market Assessment. Together they will build a more complete picture of the opportunities and challenges that await this emerging concept. Further outputs will be available from https://elstove.com/innovate-reports/ and www.MECS.org.uk.

This research is funded by DfID/UK Aid, EPSRC, RCUK & DECC (now BEIS) through the USES programme.

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9 Appendix

9.1 Appendix A: Problem statement and background to LCT eCook project

9.1.1 Beyond business as usual

The use of biomass and solid fuels for cooking is the everyday experience of nearly 3 Billion people. This pervasive use of solid fuels—including wood, coal, straw, and dung—and traditional cookstoves results in high levels of household air pollution, extensive daily drudgery required to collect fuels, and serious health impacts. It is well known that open fires and primitive stoves are inefficient ways of converting energy into heat for cooking. The average amount of biomass cooking fuel used by a typical family can be as high as two tons per year. Indoor biomass cooking smoke also is associated with a number of diseases, including acute respiratory illnesses, cataracts, heart disease and even cancer. Women and children in particular are exposed to indoor cooking smoke in the form of small particulates up to 20 times higher than the maximum recommended levels of the World Health Organization. It is estimated that smoke from cooking fuels accounts for nearly 4 million premature deaths annually worldwide – more than the deaths from malaria and tuberculosis combined.

While there has been considerable investment in improving the use of energy for cooking, the emphasis so far has been on improving the energy conversion efficiency of biomass. Indeed in a recent overview of the state of the art in Improved Cookstoves (ICS), ESMAP & GACC (2015), World Bank (2014), note that the use of biomass for cooking is likely to continue to dominate through to 2030.

> "Consider, for a moment, the simple act of cooking. Imagine if we could change the way nearly five hundred million families cook their food each day. It could slow climate change, drive gender equality, and reduce poverty. The health benefits would be enormous." ESMAP & GACC (2015)

The main report goes on to say that "The "business-as-usual" scenario for the sector is encouraging but will fall far short of potential." (ibid,) It notes that without major new interventions, over 180 million households globally will gain access to, at least, minimally improved[1] cooking solutions by the end of the

[1] A minimally improved stove does not significantly change the health impacts of kitchen emissions. "For biomass cooking, pending further evidence from the field, significant health benefits are possible only with the highest quality fan gasifier stoves; more moderate health impacts may be realized with natural draft gasifiers and vented intermediate ICS" (ibid)

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decade. However, they state that this business-as-usual scenario will still leave over one- half (57%) of the developing world's population without access to clean cooking in 2020, and 38% without even minimally improved cooking solutions. The report also states that 'cleaner' stoves are barely affecting the health issues, and that only those with forced gasification make a significant improvement to health. Against this backdrop, there is a need for a different approach aimed at accelerating the uptake of truly 'clean' cooking.

Even though improved cooking solutions are expected to reach an increasing proportion of the poor, the absolute numbers of people without access to even 'cleaner' energy, let alone 'clean' energy, will increase due to population growth. The new Sustainable Development Goal 7 calls for the world to "ensure access to affordable, reliable, sustainable and modern energy for all". Modern energy (electricity or LPG) would indeed be 'clean' energy for cooking, with virtually no kitchen emissions (other than those from the pot). However, in the past, modern energy has tended to mean access to electricity (mainly light) and cooking was often left off the agenda for sustainable energy for all.

Even in relation to electricity access, key papers emphasise the need for a step change in investment finance, a change from 'business as usual'. IEG World Bank Group (2015) note that 22 countries in the Africa Region have less than 25 percent access, and of those, 7 have less than 10 percent access. Their tone is pessimistic in line with much of the recent literature on access to modern energy, albeit in contrast to the stated SDG7. They discuss how population growth is likely to outstrip new supplies and they argue that "unless there is a big break from recent trends the population without electricity access in Sub-Saharan Africa is projected to increase by 58 percent, from 591 million in 2010 to 935 million in 2030." They lament that about 40% of Sub-Saharan Africa's population is under 14 years old and conclude that if the current level of investment in access continues, yet another generation of children will be denied the benefits of modern service delivery facilitated by the provision of electricity (IEG World Bank Group, 2015).

> "Achieving universal access within 15 years for the low-access countries (those with under 50 percent coverage) requires a quantum leap from their present pace of 1.6 million connections per year to 14.6 million per year until 2030." (ibid)

Once again, the language is a call for a something other than business as usual. The World Bank conceives of this as a step change in investment. It estimates that the investment needed to really address global electricity access targets would be about $37 billion per year, including erasing generation deficits and additional electrical infrastructure to meet demand from economic growth. "By

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comparison, in recent years, low-access countries received an average of $3.6 billion per year for their electricity sectors from public and private sources" (ibid). The document calls for the Bank Group's energy practice to adopt a new and transformative strategy to help country clients orchestrate a national, sustained, sector-level engagement for universal access.

In the following paragraphs, we explore how increasing access to electricity could include the use of solar electric cooking systems, meeting the needs of both supplying electricity and clean cooking to a number of households in developing countries with sufficient income.

9.1.2 Building on previous research

Gamos first noted the trends in PV and battery prices in May 2013. We asked ourselves the question, is it now cost effective to cook with solar photovoltaics? The answer in 2013 was 'no', but the trends suggested that by 2020 the answer would be yes. We published a concept note and started to present the idea to industry and government. Considerable interest was shown but uncertainty about the cost model held back significant support. Gamos has since used its own funds to undertake many of the activities, as well as IP protection (a defensive patent application has been made for the battery/cooker combination) with the intention is to make all learning and technology developed in this project open access, and awareness raising amongst the electrification and clean cooking communities (e.g. creation of the infographic shown in Figure 21 to communicate the concept quickly to busy research and policy actors).

Gamos has made a number of strategic alliances, in particular with the University of Surrey (the Centre for Environmental Strategy) and Loughborough University Department of Geography and seat of the Low Carbon Energy for Development Network). In October 2015, DFID commissioned these actors to explore assumptions surrounding solar electric cooking[2] (Batchelor, 2015b; Brown and Sumanik-Leary, 2015; Leach and Oduro, 2015; Slade, 2015). The commission arose from discussions between consortium members, DFID, and a number of other entities with an interest in technological options for cleaner cooking e.g. Shell Foundation and the Global Alliance for Clean Cookstoves.

Drawing on evidence from the literature, the papers show that the concept is technically feasible and could increase household access to a clean and reliable modern source of energy. Using a bespoke economic model, the Leach and Oduro paper also confirm that by 2020 a solar based cooking system

[2] The project has been commissioned through the PEAKS framework agreement held by DAI Europe Ltd.

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could be comparable in terms of monthly repayments to the most common alternative fuels, charcoal and LPG. Drawing on published and grey literatures, many variables were considered (e.g. cooking energy needs, technology performance, component costs). There is uncertainty in many of the parameter values, including in the assumptions about future cost reductions for PV and batteries, but the cost ranges for the solar system and for the alternatives overlap considerably. The model includes both a conservative 5% discount rate representing government and donor involvement, and a 25% discount rate representing a private sector led initiative with a viable return. In both cases, the solar system shows cost effectiveness in 2020.

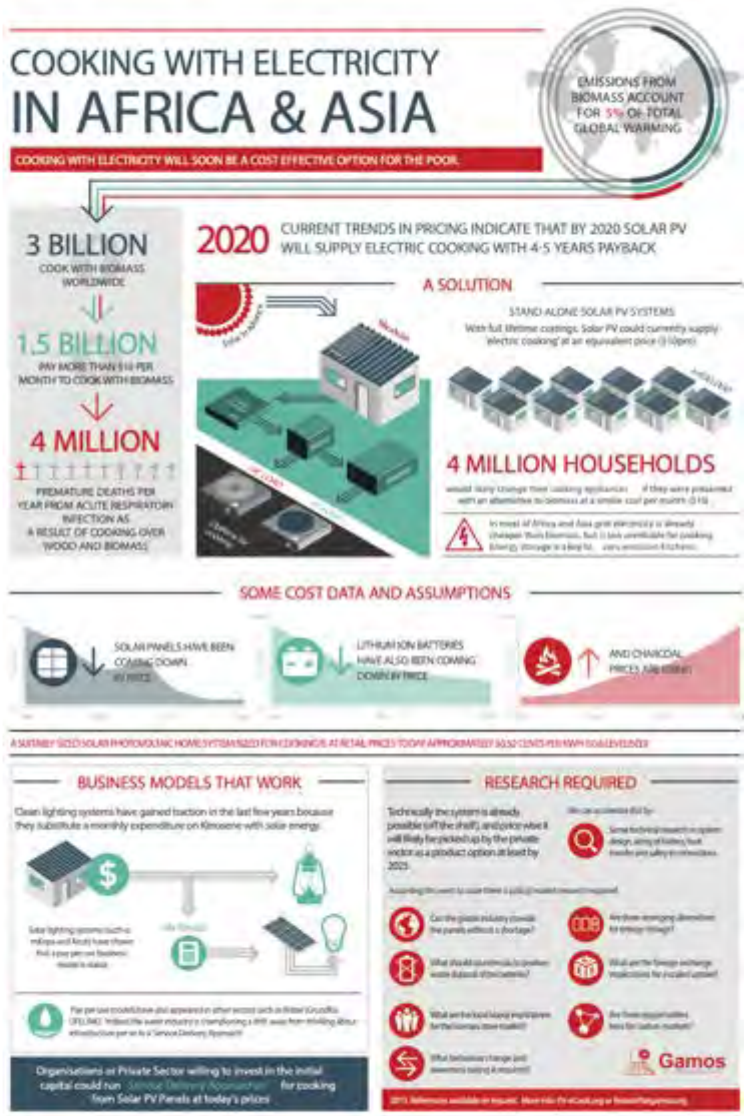

Figure 21 Infographic summarising the concept in order to lobby research and policy actors.

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The Brown and Sumanik-Leary paper in the series examines the lessons learned from four transitions – the uptake of electric cooking in South Africa, the roll out of Improved Cookstoves (ICS), the use of LPG and the uptake of Solar Home Systems (SHS). They present many behavioural concerns, none of which preclude the proposition as such, but all of which suggest that any action to create a scaled use of solar electric cooking would need in depth market analysis; products that are modular and paired with locally appropriate appliances; the creation of new, or upgrading of existing, service networks; consumer awareness raising; and room for participatory development of the products and associated equipment.

A synthesis paper summarising the above concludes by emphasising that the proposition is not a single product – it is a new genre of action and is potentially transformative. Whether solar energy is utilised within household systems or as part of a mini, micro or nano grid, linking descending solar PV and battery costs with the role of cooking in African households (and the Global South more broadly) creates a significant potential contribution to SDG7. Cooking is a major expenditure of 500 million households. It is a major consumer of time and health. Where households pay for their fuelwood and charcoal (approximately 300 Million) this is a significant cash expense. Solar electric cooking holds the potential to turn this (fuelwood and charcoal) cash into investment in modern energy. This "consumer expenditure" is of an order of magnitude more than current investment in modern energy in Africa and to harness it might fulfil the calls for a step change in investment in electrical infrastructure.

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9.1.3 Summary of related projects

A series of inter-related projects have led to and will follow on from the research presented in this report:

- Gamos Ltd.'s early conceptual work on eCook (Batchelor, 2013).
    - The key **CONCEPT NOTE** can be found here.
    - An early infographic and a 2018 infographic can be found here.
- Initial technical, economic and behavioural feasibility studies on eCook commissioned by DfID (UK Aid) through the CEIL-PEAKS Evidence on Demand service and implemented by Gamos Ltd., Loughborough University and University of Surrey.
    - The key **FINAL REPORTS** can be found here.
- Conceptual development, stakeholder engagement & prototyping in Kenya & Bangladesh during the "*Low cost energy-efficient products for the bottom of the pyramid*" project from the USES programme funded by DfID (UK Aid), EPSRC & DECC (now part of BEIS) & implemented by University of Sussex, Gamos Ltd., ACTS (Kenya), ITT & UIU (Bangladesh).
    - The key **PRELIMINARY RESULTS** (Q1 2019) can be found here.
- A series of global & local market assessments in Myanmar, Zambia and Tanzania under the "*eCook - a transformational household solar battery-electric cooker for poverty alleviation*" project funded by DfID (UK Aid) & Gamos Ltd. through Innovate UK's Energy Catalyst Round 4, implemented by Loughborough University, University of Surrey, Gamos Ltd., REAM (Myanmar), CEEEZ (Zambia) & TaTEDO (Tanzania).
    - The key **PRELIMINARY RESULTS** (Q1 2019) can be found here.
- At time of publication (Q1 2019), a new DfID (UK Aid) funded research programme '*Modern Energy Cooking Services*' (MECS) lead by Prof. Ed Brown at Loughborough University is just beginning and will take forward these ideas & collaborations.

This data and material have been funded by UK AID from the UK government; however, the views expressed do not necessarily reflect the UK government's official policies.

9.1.4 About the Modern Energy Cooking Services (MECS) Programme.

Sparking a cooking revolution: catalysing Africa's transition to clean electric/gas cooking.

www.mecs.org.uk | mecs@lboro.ac.uk

Modern Energy Cooking Services (MECS) is a five-year research and innovation programme funded by UK Aid (DFID). MECS hopes to leverage investment in renewable energies (both grid and off-grid) to address the clean cooking challenge by integrating modern energy cooking services into the planning for access to affordable, reliable and sustainable electricity.

Existing strategies are struggling to solve the problem of unsustainable, unhealthy but enduring cooking practices which place a particular burden on women. After decades of investments in improving biomass cooking, focused largely on increasing the efficiency of biomass use in domestic stoves, the technologies developed are said to have had limited impact on development outcomes. The Modern Energy Cooking Services (MECS) programme aims to break out of this "business-as-usual" cycle by investigating how to rapidly accelerate a transition from biomass to genuinely 'clean' cooking (i.e. with electricity or gas).

Worldwide, nearly three billion people rely on traditional solid fuels (such as wood or coal) and technologies for cooking and heating[3]. This has severe implications for health, gender relations, economic livelihoods, environmental quality and global and local climates. According to the World Health Organization (WHO), household air pollution from cooking with traditional solid fuels causes to 3.8 million premature deaths every year – more than HIV, malaria and tuberculosis combined[4]. Women and children are disproportionately affected by health impacts and bear much of the burden of collecting firewood or other traditional fuels.

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[3] http://www.who.int/indoorair/health_impacts/he_database/en/

[4] https://www.who.int/en/news-room/fact-sheets/detail/household-air-pollution-and-health https://www.who.int/gho/hiv/epidemic_status/deaths_text/en/, https://www.who.int/en/news-room/fact-sheets/detail/malaria, https://www.who.int/en/news-room/fact-sheets/detail/tuberculosis

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Greenhouse gas emissions from non-renewable wood fuels alone total a gigaton of CO_2e per year (1.9-2.3% of global emissions)[5]. The short-lived climate pollutant black carbon, which results from incomplete combustion, is estimated to contribute the equivalent of 25 to 50 percent of carbon dioxide warming globally – residential solid fuel burning accounts for up to 25 percent of global black carbon emissions[6]. Up to 34% of woodfuel harvested is unsustainable, contributing to climate change and local forest degradation. In addition, approximately 275 million people live in woodfuel depletion 'hotspots' – concentrated in South Asia and East Africa – where most demand is unsustainable[7].

Africa's cities are growing – another Nigeria will be added to the continent's total urban population by 2025[8] which is set to double in size over the next 25 years, reaching 1 billion people by 2040. Within urban and peri-urban locations, much of Sub Saharan Africa continues to use purchased traditional biomass and kerosene for their cooking. Liquid Petroleum Gas (LPG) has achieved some penetration within urban conurbations, however, the supply chain is often weak resulting in strategies of fuel stacking with traditional fuels. Even where electricity is used for lighting and other amenities, it is rarely used for cooking (with the exception of South Africa). The same is true for parts of Asia and Latin America. Global commitments to rapidly increasing access to reliable and quality modern energy need to much more explicitly include cooking services or else household and localized pollution will continue to significantly erode the well-being of communities.

Where traditional biomass fuels are used, either collected in rural areas or purchased in peri urban and urban conurbations, they are a significant economic burden on households either in the form of time or expenditure. The McKinsey Global Institute outlines that much of women's unpaid work hours are spent on fuel collection and cooking[9]. The report shows that if the global gender gap embodied in such activities were to be closed, as much as $28 trillion, or 26 percent, could be added to the global annual

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[5] Nature Climate Change 5, 266–272 (2015) doi:10.1038/nclimate2491

[6] http://cleancookstoves.org/impact-areas/environment/

[7] Nature Climate Change 5, 266–272 (2015) doi:10.1038/nclimate2491

[8] https://openknowledge.worldbank.org/handle/10986/25896

[9] McKinsey Global Institute. *The Power of Parity: How Advancing Women's Equality can add $12 Trillion to Global Growth*; McKinsey Global Institute: New York, NY, USA, 2015.

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GDP in 2025. Access to modern energy services for cooking could redress some of this imbalance by releasing women's time into the labour market.

To address this global issue and increase access to clean cooking services on a large scale, investment needs are estimated to be at least US$4.4 billion annually[10]. Despite some improvements in recent years, this cross-cutting sector continues to struggle to reach scale and remains the least likely SE4All target to be achieved by 2030[11], hindering the achievement of the UN's Sustainable Development Goal (SDG) 7 on access to affordable, reliable, sustainable and modern energy for all.

Against this backdrop, MECS draws on the UK's world-leading universities and innovators with the aim of sparking a revolution in this sector. A key driver is the cost trajectories that show that cooking with (clean, renewable) electricity has the potential to reach a price point of affordability with associated reliability and sustainability within a few years, which will open completely new possibilities and markets. Beyond the technologies, by engaging with the World Bank (ESMAP), MECS will also identify and generate evidence on other drivers for transition including understanding and optimisation of multi-fuel use (fuel stacking); cooking demand and behaviour change; and establishing the evidence base to support policy enabling environments that can underpin a pathway to scale and support well understood markets and enterprises.

The five-year programme combines creating a stronger evidence base for transitions to modern energy cooking services in DFID priority countries with socio-economic technological innovations that will drive the transition forward. It is managed as an integrated whole; however, the programme is contracted via two complementary workstream arrangements as follows:

- An Accountable Grant with Loughborough University (LU) as leader of the UK University Partnership.
- An amendment to the existing Administrative Arrangement underlying DFID's contribution to the ESMAP Trust Fund managed by the World Bank.

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[10] The SE4ALL Global Tracking Report shows that the investment needed for universal access to modern cooking (not including heating) by 2030 is about $4.4 billion annually. In 2012 investment was in cooking was just $0.1 billion. Progress toward Sustainable Energy: Global Tracking Report 2015, World Bank.

[11] The 2017 SE4All Global Tracking Framework Report laments that, "Relative to electricity, only a small handful of countries are showing encouraging progress on access to clean cooking, most notably Indonesia, as well as Peru and Vietnam."

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The intended outcome of MECS is a market-ready range of innovations (technology and business models) which lead to improved choice of affordable and reliable modern energy cooking services for consumers. Figure 22 shows how the key components of the programme fit together. We will seek to have the MECS principles adopted in the SDG 7.1 global tracking framework and hope that participating countries will incorporate modern energy cooking services in energy policies and planning.

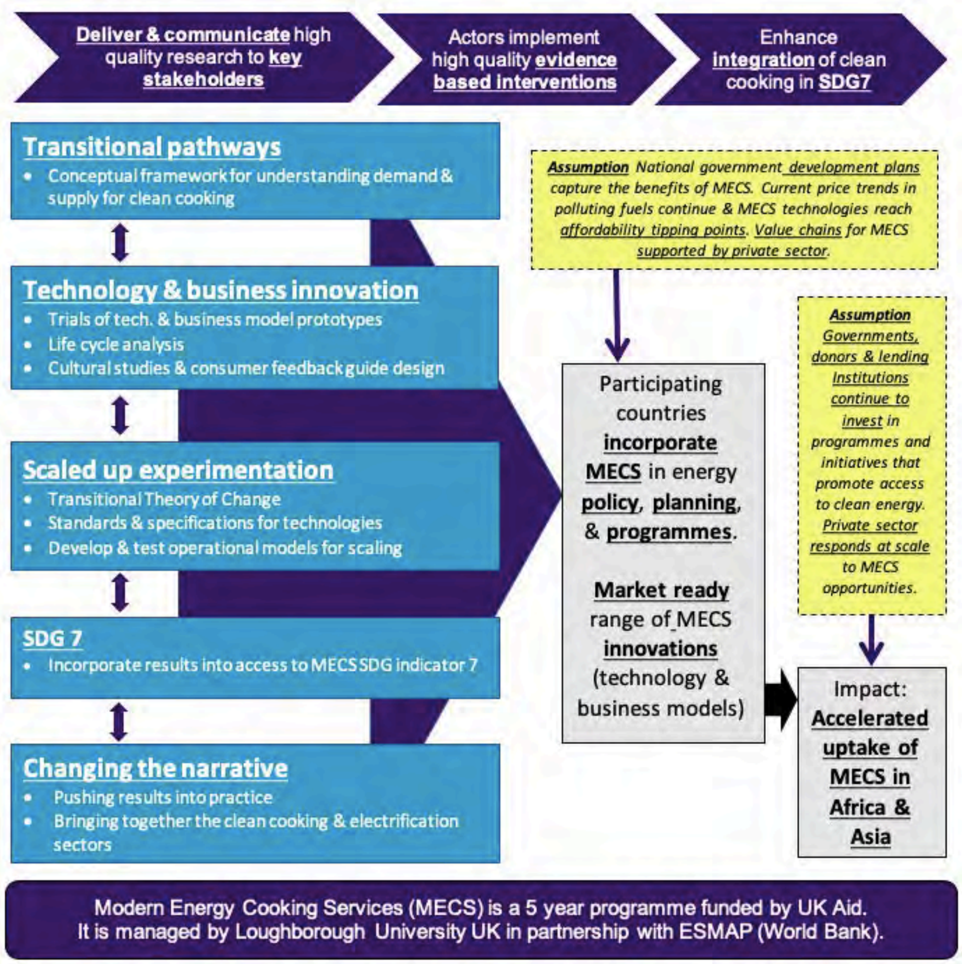

Figure 22: Overview of the MECS programme.